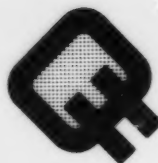


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OUTGASSING AND HEAT LOSS IN POLYURETHANE FOAM INSULATED ELECTRIC HOT WATER TANKS

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ABSTRACT

This report presents the results of a program to analyze the outgassing of chemical products from blown-in polyurethane foam insulated electric water heaters and to evaluate the changes in thermal performance of the insulation from aging. The results indicate that the loss of thermal performance is extremely small and there is little reason for concern for indoor air quality, as the products of outgassing were negligible amounts of CFCs and organic impurities.

job	file	date	report no.
32-289-111	835.41141	July 24, 1989	89-150-K



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EXECUTIVE SUMMARY

OUTGASSING AND HEAT LOSS IN POLYURETHANE FOAM INSULATED ELECTRIC HOT WATER TANKS

G. Gowda

Polyurethane foam (PUF) is presently used by a number of manufacturers as alternative insulation for fiberglass in domestic water heaters. The PUF insulation allows a thinner, more rigid tank which is easier to carry into a home by the installation crews, and provides higher thermal resistance (R) with approximately half the thickness required for fiberglass insulation.

The municipal electric utilities have expressed concern about the use of PUF in electrical water heaters regarding both its safety and longevity. Safety is related to the degree if any of the outgassing of noxious chemicals and the concern over longevity is related to the degree if any of the gradual reduction over time of R value if the freon was to diffuse out of the foam cells.

Experiments were designed to measure outgassing and loss of thermal resistance from five tanks operated in draw-down and continuous modes, representing worst case conditions. Analysis of outgasses indicated that they contained only trichlorofluoromethane and xylenes. The total amounts of those chemicals released over a period of 12 months were 3.4 mg and 0.06 mg respectively. Their concentration would be far below the residential threshold limit values even if they are released all at once (<0.6% of TLV for trichlorofluoromethane and <0.14% of TLV for xylenes).

The changes in thermal performance of the PUF insulation from aging was evaluated by measuring the standby energy loss, in accordance with CSA C191-M1983, before and after the experimental program. Although there was an increase in standby loss, the percentage change was small.



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**OUTGASSING AND HEAT LOSS IN POLYURETHANE
FOAM INSULATED ELECTRIC HOT WATER TANKS**

G. Gowda

1.0 INTRODUCTION

The rapid transition from fiberglass thermal insulation to polyurethane foam (PUF) insulation in electrically heated domestic hot water tanks has reached about 60% of new shipments by one of Ontario's major manufacturers of this product.

The municipal electric utilities have expressed concern about the use of PUF in electrical water heaters regarding both its safety and longevity. Safety is related to the degree if any of the outgassing of noxious chemicals and the concern over longevity is related to the degree if any of the gradual reduction over time of R value if the freon was to diffuse out of the foam cells.

At the request of the Residential and Agricultural Programs Department, a project was undertaken to develop information on the nature of any chemicals released and the effect on thermal resistance of the aged PUF insulation in electrically heated water tanks. This report contains the results of the program which was carried out over a twelve month period by the Chemical Research Department.

2.0 BACKGROUND

Polyurethane foam (PUF) is presently used by a number of manufacturers as alternative insulation for fiberglass in domestic water heaters. The PUF insulation allows a thinner, more rigid tank which is easier to carry into a home by the installation crews, and provides higher thermal resistance with approximately half the thickness required for fiberglass insulation.

Polyurethane is made by mixing stoichiometric amounts of a polyisocyanate and a polyhydroxyl ether or ester /1/. These components may contain a catalyst, a surface active agent, and a blowing agent - which is normally a halocarbon refrigerant. Each component may also contain minor constituents such as methylstyrene, cyclohexane, N,N-dimethylcyclohexylamine, toluene, chlorobenzene and other organic materials which are impurities in the base materials or are added to act as stabilizers, fire retardants, cell structure modifiers or processing aids. These minor constituents do not react with or enter into the reaction of the polyisocyanate and polyhydroxyl that form the polyurethane. As the two main components react during mixing, the resulting heat causes the blowing agent to vaporize, thereby producing the foam structure. Since the cells of the foam contain halocarbon gas, a more efficient thermal insulator than air /2/, a foam is created with a high thermal resistance. Although PUF is dimensionally stable at low temperatures and in dry conditions, exposure to a temperature greater than 50°C and relative humidities greater than 90% can cause it to become dimensionally unstable. This is due to the plasticizing of the foam structure by water and the expansion of the residual blowing agent in the cells caused by the increase in temperature. With thermally weakened cell walls and greater pressure-stress across them, rupture of the cell walls and an increase in the mass transfer or diffusion of volatile components across or through them could be expected to occur leading to outgassing. Furthermore, the outgassing of the halogenated propellant could have a detrimental effect on the thermal resistance of the aged insulating material.

3.0 DESCRIPTION OF EXPERIMENTAL SET UP

Five water tanks (four metal and one plastic) insulated with 50 mm PUF were used in the study. The metal water tanks (1x272L and 3x175L capacity) contain a glass lining, carbon steel pressure vessel and metal casing, whereas the plastic tank (185L capacity) contains a polybutylene liner, glassfiber pressure vessel and plastic casing. Three tanks (two metal and one plastic) were enclosed in an air-tight steel shroud, fitted with a sampling port, to trap any gasses released from the PUF insulation. The remaining two metal tanks were set-up to represent operating conditions similar to those existing in residential dwellings. All water tanks were operated at maximum thermostat setting (~77°C) for the duration of the study. Energy consumption and water temperatures of each water heater were monitored on a monthly basis via watt-hour meters and thermocouples. Gases collected cumulatively within the metal shroud were sampled monthly by displacing 1000cc of air with nitrogen gas. The chemicals present were adsorbed on a pre-conditioned Tenax TA adsorbent material by passing the displaced gas over the adsorbent (see Appendix A). The nature of

the chemicals and their cumulative quantities were determined using a capillary Gas Chromatography-Mass Spectrometer by direct thermal desorption technique.

In addition to monitoring the energy consumption on a monthly basis, the Energy Efficiency tests of the tanks were conducted as per CSA C191-M1983 /3/ (Appendix B) before the tanks were put into operation and then again after twelve months of operation.

4.0 RESULTS AND DISCUSSION

4.1 Analysis of Outgasses from PUF Insulated Electric Hot Water Tanks

Prior to analyzing the gases released from the water heater insulation, it was necessary to determine the nature of the chemicals present in the PUF. This was done by directly heating a reference PUF sample at 100°C for 3 days and identifying the chemicals as per the procedure given in Appendix C. Table I lists the chemicals outgassed from a reference PUF sample, representing the chemicals expected to be released from the insulation of the water heaters if outgassing occurs at a similar rate. In addition to the halocarbon blowing species of chemicals such as the Freon-11 family of chlorofluoromethane and 1,2-dichloroethane, Table I shows that materials such as methyl styrene, xylenes, N,N-dimethyl cyclohexanamine, bipheneyl dimethyl and chlorocyclohexane were present /4,5/. These materials are judged to be of concern to health by the American Conference of Governmental Industrial Hygienists (ACGIH) /6/.

In contrast, the analysis of outgases collected from the hot water tanks insulation, under maximum allowable operating conditions, revealed only two of the 14 chemicals that were present in a reference PUF sample. The names and total amounts of the chemicals outgassed over a twelve month period are given in Table II. The highest total amount of trichlorofluoromethane and xylenes released from any one hot water tank was 3.4 mg and 0.06 mg respectively. Furthermore, outgassing of xylenes was complete within one month of operation and outgassing of trichlorofluoromethane reached its maximum around six months (Figure 1).

Trichlorofluoromethane, a component of CFC propellant gas, and xylenes, a class of aromatic hydrocarbons, are classified as hazardous by the ACGIH and a Threshold Limit Value (TLV) is set

* TLV is defined as the time-weighted average concentration for a normal 8-hour work day and a 40-hour work week, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

TABLE I

Chemicals Released From a Reference PUF Sample

1. Trichlorofluoromethane
2. Cyclohexanamine, N,N-Dimethyl
3. Benzene (1-Methyl Ethenyl)
4. Ethane, 1-Phenyl
5. Dichloro Tetrafluoroethane
6. Benzoic Acid, 4-Methyl Hydrazide
7. Cyclohexane, 1-Chloro-5(1-Chloroethenyl)
8. 1,3-Butadiene, 2-Chloro Dimer
9. Butyl Octanol
10. Cyclo-Octadiene, 1,6-Dichloro
11. Isobenzofuranone
12. Biphenyl, 3-4-Dimethyl
13. Xylenes
14. Benzenedicarboxylic Acid Butyl Octyl Ester

TABLE II

Chemicals Released From the Water Tank PUF Insulation

<u>Name</u>	<u>Total Outgassing in one year</u>
Trichlorofluoromethane	3.4 mg
Xylenes	0.06 mg

at 5600 and 435 milligrams per cubic meter of air in work place for the trichlorofluoromethane and xylenes respectively /6/. However, the residential TLVs are set at 10% of the work place by the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) /7/. Therefore the allowable concentration limits in a residential dwelling according to ASHRAE is 560mg/m³ and 43.5mg/m³ for trichlorofluoromethane and xylenes respectively.

In view of these guidelines, the outgassing rates from PUF insulation in hot water tanks are well below any potential toxic level in a residence or apartment. It is also worth noting that even if all of the trichlorofluoromethane and xylenes were released at once, the concentration levels would be far below the allowable limits.

4.2 Evaluation of Changes in Thermal Performance of Aged PUF Insulated Electric Hot Water Tanks

The changes in thermal resistance (or insulation efficiency) of PUF insulated electric hot water tanks was measured by performing CSA Energy Efficiency tests at the beginning and end of the experimental program (Appendix B). The initial standby energy loss was well below the the CSA C191-M1983 requirement of 100 watts maximum for a 175-litre tank and 115 watts maximum for a 270-litre tank. After heating the tanks at the maximum thermostat setting (77°C) for a twelve month period, there was an increase in the standby energy loss. The results of standard Energy Efficiency tests are given in Figure 2 and Table III. The increase in energy loss for the 5 tanks ranged from 4% to 12.5% over a 12 month period. Furthermore, even with the increase in thermal energy loss, they were still within the requirements of CSA C191.

In addition to measuring the overall energy loss according to CSA C191, standby loss was also monitored by recording the energy consumption of each tank on a monthly basis. The results shown in Figure 3 indicate that the energy loss increased gradually over the 12 month period which is consistent with the CSA standard test results shown in Figure 2. The difference between the graphs in Figure 2 and 3 is attributed to fluctuations in ambient temperature during the monthly monitoring of energy consumption. The daily fluctuations in room temperature were not accounted for in the standby loss calculated using the monthly data.

FIGURE 1

OUTGASSING OF TRICHLOROFLUOROMETHANE FROM
PUF INSULATED ELECTRIC WATER HEATERS

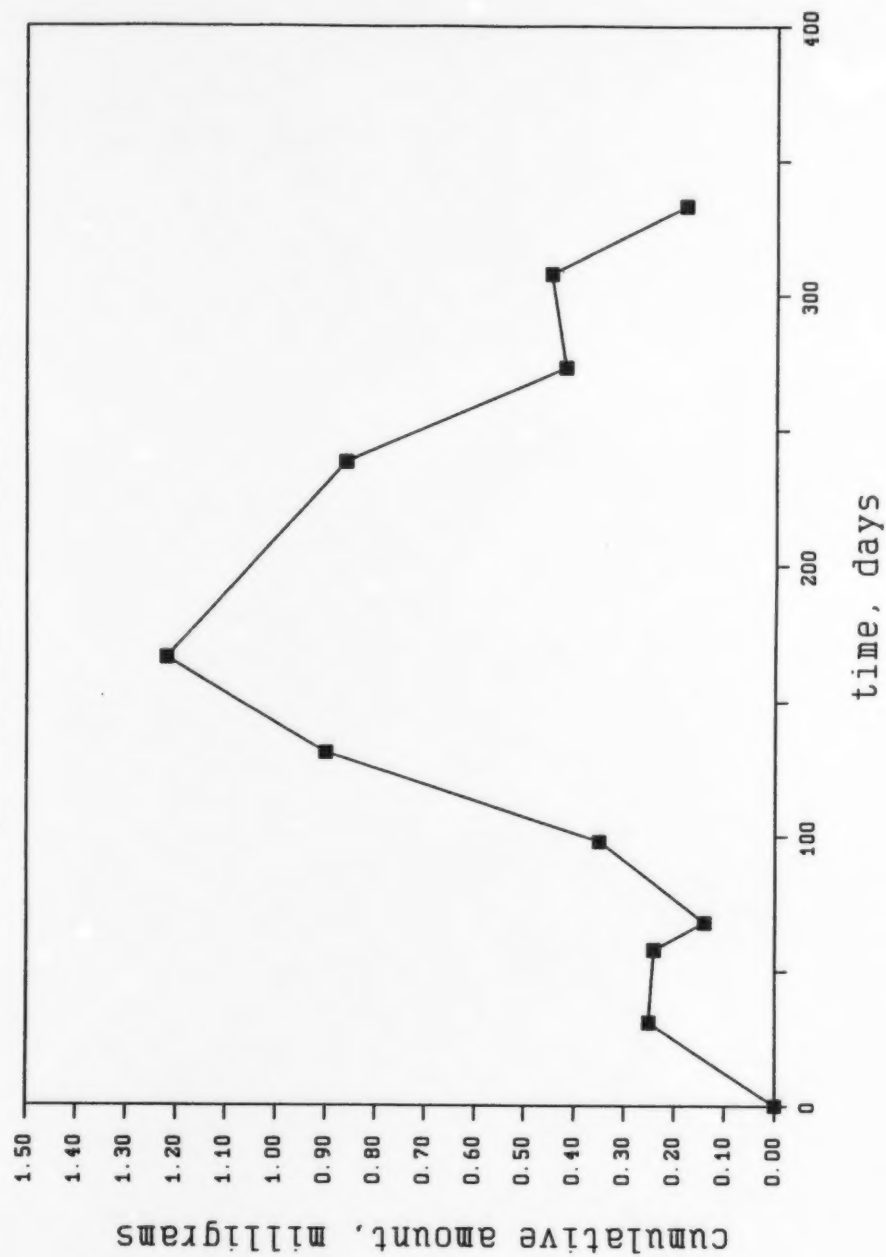


FIGURE 2
CSA C191 ENERGY EFFICIENCY TESTS

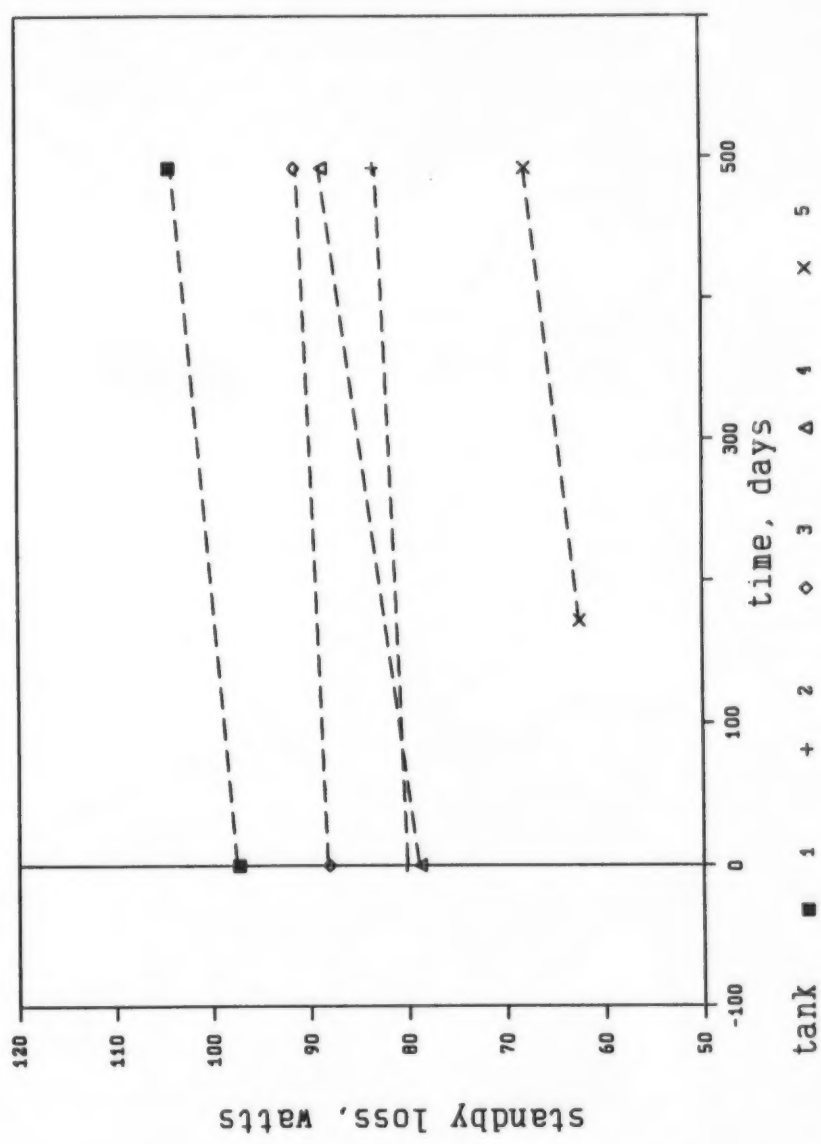


FIGURE 3

Monthly Standby Loss

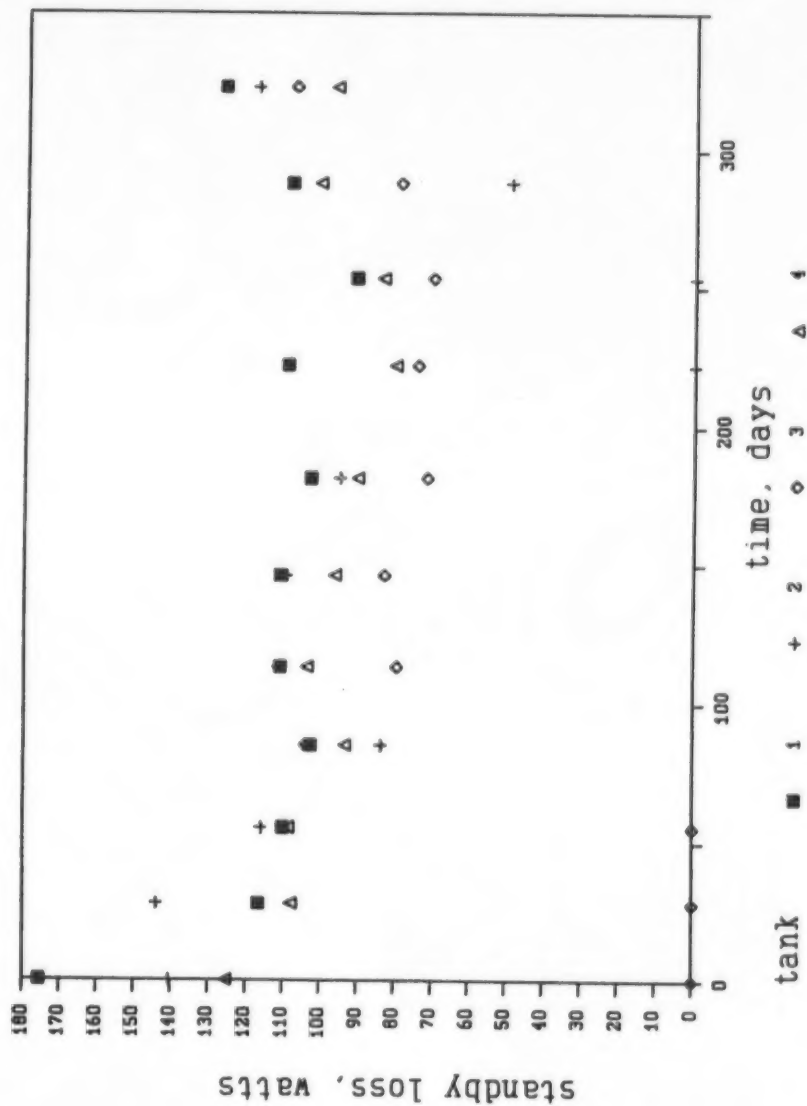


Table III

CSA Standby Loss Measurements

Tank No.	Standby Loss, Watts		Percent Change
	Before	After 12 Months Service	
1 (272 L)	97.34	104.3	+7
2 (175 L)	80.21	83.3	+4
3 (175 L)	88.05	91.4	+4
4 (175 L)	78.78	88.6	+12.5
5 (185 L)*	62.5	67.8	+8.5

*Plastic

Note: Standby loss allowed for a new tank by CSA:
270 Litres = 115 W / 175 Litres = 100 W

5.0 CONCLUSIONS

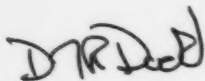
After heating the PUF insulated electric hot water tanks at 77°C (normal operating temperature of domestic hot water tanks is 60°C) for a period of twelve months, 3.4 mg of trichlorofluoromethane, a component of Freon-11, and 0.06 mg of xylenes, an organic impurity, were found to be present in the outgasses. The amounts released are far below the allowable TLVs in a residential dwelling: 560 mg/m³ for trichlorofluoromethane and 43.5 mg/m³ for xylenes. Furthermore, even if these chemicals were released all at once, the air concentration would not exceed the residential TLVs.

A gradual increase in standby energy loss of the aged PUF insulation in the electric hot water tanks was observed. However, this increase after one year of operation is quite low considering the tanks were operated at their maximum thermostat setting (77°C). Moreover, even with the observed increase, the standby loss of each tank was still within the CSA requirements.

ACKNOWLEDGEMENTS

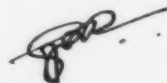
I would like to thank Mr. M. Perlman and Mr. N.H. Milligan of the Electrical Research Department for coordinating the CSA Energy Efficiency test measurements; Mr. Dave Mueller of the Materials Chemistry Section for his work in the laboratory.

Approved by:



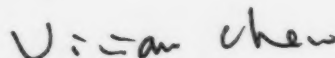
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6.0 REFERENCES

1. Hallinan, M.R., Himmler, M.R., Kaplan, M., "Recent Advances in the Technology of Rigid Urethane Foams," paper presented at the Eighteenth Annual Conference of the Society of Plastic Engineers, Inc., Pittsburgh Pa., February 2, 1962.
2. Ball, G.W., Hurd, R., Walker, M.G., "Thermal Conductivity of Rigid Urethane Foam," Journal of Cellular Plastics, Vol 6, No 2, 1970.
3. CSA Standards on Performance of Electric Storage Tank water Heaters, Nov 19, 1983.
4. Krzymien, M.E., "Analysis of the Effluents from Polyurethane Foam Insulation," National Research Council, National Aeronautical Establishment, Ottawa, Ontario.
5. Alkhoury, E., Gibbons, C.S., "Evaluation of Foamed-in-Place Polyurethane in Exterior Walls of R-2000 Homes". by Ontario Research Foundation.
6. American Conference of Governmental Industrial Hygienists, "Threshold Limit Values and Biological Exposure Indices for 1988-1989".
7. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., "Ventilation for Acceptable Indoor Air Quality", July 15, 1986.

APPENDIX A

Procedure for Sampling and Analysis of Outgasses From Hot Water Tanks

The materials released from the PUF insulation of the water tanks were cumulatively collected within a shroud built around the tanks. These materials were sampled by displacing 1000cc of air within the shroud by nitrogen and adsorbing it over a preconditioned adsorbing material. The adsorbing material used was Tenax TA (35/60 mesh) purchased from Chromatographic Specialties INC. The adsorbant was conditioned by heating it in a clean stainless steel tube at 350°C for 4 hours under ultra high purity helium at 100°C.

The chemicals were thermally desorbed from the adsorbent and analyzed using capillary gas chromatography and mass spectrometer under the following parameters:

GC Parameters

Column - 60 M x 0.75 MM ID, 1.5µm film Yoccol Capillary Column.
Column Temp - 45°C (4min) to 220°C at 6°C/min
Detector Temp - 250°C
Injector Temp - 250°C
Trap Temp - 210°C
Desorber Temp - 210°C

MS Parameters

Mass Scan - 45-400 at 1.0 second/scan
Emission I - 0.5 Ma
Electron E - 70 ev
Ionizer Temp - 270°C
EM voltage - 1500 volts

APPENDIX B

Standby Energy Loss Measurements

The Energy Efficiency tests were conducted in accordance with clause 5.6 of the CSA standard C191-M1983, "Performance of Electric Storage Tank Water Heaters", and the details of the procedure are given below.

Energy Efficiency Test

The thermostats shall be set at 68°C. The water heater shall be energized and operated with no withdrawals of water. After the lower thermostat has cut out for the first time (start of "idling" period) its setting shall be adjusted to give a top-of-tank temperature of 68°C and the accumulated air shall be eliminated. The water heater shall be operated under these idling conditions for at least 72 h. Water temperatures indicated by the thermocouple probe shall be recorded continuously.

At a thermostat cut-out approximately 24 h after the start of the "idling" period, the water temperatures and the indication of the watt-hour meter shall be noted. These readings shall be repeated at the first thermostat cut-out following an additional period of at least 48 h.

The average standby loss for a 44°C rise above room temperature shall be calculated as follows

$$\text{watts loss} = \frac{1.163V(T_1 - T_2) + Wh}{N} \times \frac{44}{T_T - T_R}$$

where

V = actual tank capacity in litres

T₁ = average water temperature at start of test in degrees Celsius

T₂ = average water temperature at finish of test in degrees Celsius

Wh = measured energy consumption in watthours

N = number of hours of test, ie., time interval between watthour meter readings

T_R = average measured room temperature during test and shall be the average of values recorded at 2 h intervals

T_T = average water temperature during test and shall be the average of average tank temperatures (Clause 5.2.3.5) calculated at 2 h intervals.

APPENDIX C

Outgassing of Reference PUF samples

A representative PUF insulation sample was obtained from a domestic water tank. The PUF sample was broken into small pieces and placed into a 3/8" OD 316 stainless steel tube using glass wool plugs to hold it in place. The tube containing the sample was placed in an oven with the proper connectors, flowmeter, and UHP nitrogen cylinder attached to it. A flow rate of 50cc/min of nitrogen was established. The oven was heated to 100°C and the outgasses were collected on a pre-conditioned Tenax TA adsorbent over a period of 65 hours.